

CHAPTER 22

V.H.F.-BISTATIC-AURORA COMMUNICATIONS AS A FUNCTION OF GEOMAGNETIC ACTIVITY AND MAGNETIC LATITUDE

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ABSTRACT

Observations of v.h.f.-bistatic-aurora-backscatter-communications on 145 Mc/s within Middle Europe and from Middle Europe to Great Britain and Scandinavia covering the period from 1957 to the beginning of 1963 are analyzed with respect to the probability of occurrence of these phenomena as a function of the magnetic dip angle and the degree of geomagnetic activity. An interpretation is given of the obtained results.

1. INTRODUCTION

THE influence of the aurora on v.h.f. radio waves has been recognized for some time. Radio amateurs discovered during 1939 in the U.S.A. that they were able to communicate abnormally long distances up to about 1000 km on frequencies too high to be propagated by normal modes.¹ The effect was associated with the aurora because it was most commonly noticed at times of visual aurora displays. To get a clearer picture of this phenomenon a program of amateur auroral reporting was initiated in 1951 in U.S.A. The reports were sent with the help of ARRL* to a collecting center,† where a statistical study has been attempted. Some first results are published by R. K. Moore,² further results by R. Dyce,⁴ and by N. C. Gerson.^{5, 6}

An aurorally-propagated v.h.f. signal has a characteristic growl or hiss due to a fast fading that is at an audio rate up to several hundred cycles per second.³ As the carrier frequency is increased to higher v.h.f. frequencies, the growl increases in pitch. Amplitude modulated phone signals are badly garbled although relatively slow CW-telegraphy can get through without difficulty. Reception with the switched in beat-frequency-oscillator (b.f.o.) will usually not give a clean note, so this is a sensitive test for signals propagated by aurora. Unlike *E*- or *F*-layer propagation, strongest signals are usually obtained when both stations point their directional antennas northward towards the aurora, regardless of the actual great-circle bearing between the stations. The geometry of the propagation path is shown in Fig. 1. During especially strong aurora, often accompanied by active overhead

* ARRL = American Radio Relay League, West Hartford, Conn.

† Cornell University Ionosphere Project, Franklin Hall, Ithaca, New York.

displays, the signals may appear to come from a variety of directions spread about north. Communications of the kind shown in Fig. 1 are called "bistatic aurora backscatter communications" or single "aurora contacts".

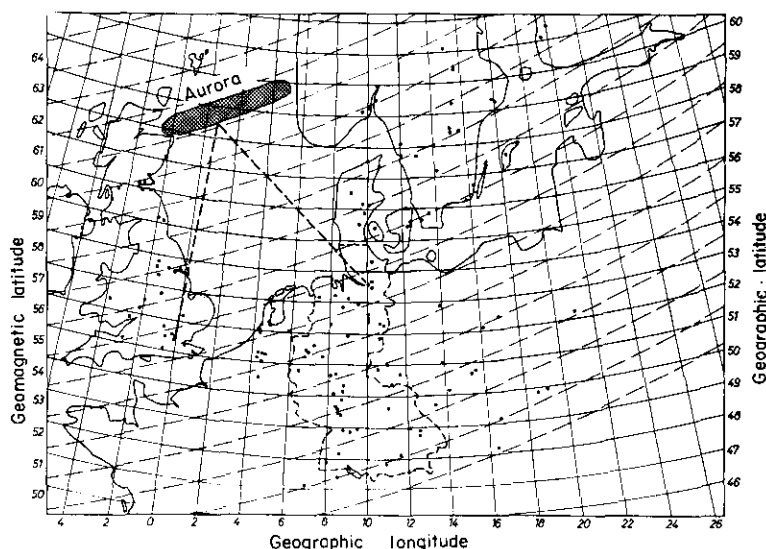


Fig. 1. Map of Middle Europe with the net of v.h.f. radio amateur stations observing and reporting bistatic aurora backscatter communications (aurora contacts) on 145 Mc/s in the time from 1957 to the beginning of 1963. The little lines are the geomagnetic parallels of latitude.

2. THE NET OF OBSERVING STATIONS

Figure 1 further shows the net of v.h.f. radio amateur stations in Middle Europe, Great Britain and Scandinavia which starts with the systematic observation and reporting of v.h.f. aurora contacts at the beginning of the IGY* and which is still running now without interruptions of the past. The net is situated between 48° and 60° geomagnetic latitude and between 63° and 74° dip angle I .† The average CW power of the v.h.f. transmitters is about 100 W and the directional antennas generally are 4–10 elements Yagi antennas. Owing to the very high sunspot activity during the IGY and the following years it was possible to observe a lot of v.h.f. aurora contacts on 145 Mc/s in these relatively low latitudes.

The worldwide observation of the visual aurora during IGY has shown that the lines of equal aurora frequency (isochasm) follow closer to the lines of equal dip angle (isoclines) than to the parallels of geomagnetic latitude.⁷ The net of Fig. 1 therefore was divided for reduction work in five zones *A, B, C, D, E* according to the dip angle of the observing stations (Fig. 2). Zone *A* is the most southern one with dip angles I from 63° to 66° . It covers

* International Geophysical Year.

† In the following called "magnetic latitude".

the region of Northern France, Southern Germany, Austria and Czechoslovakia. Zone *E* is the most northern one with dip angles from 72° to 74° . It covers the region of Southern Finland, Southern Norway and the region north of Scotland. The long term nature of the observations by the net of stations in Fig. 1 (1957–1963) has made it possible to investigate

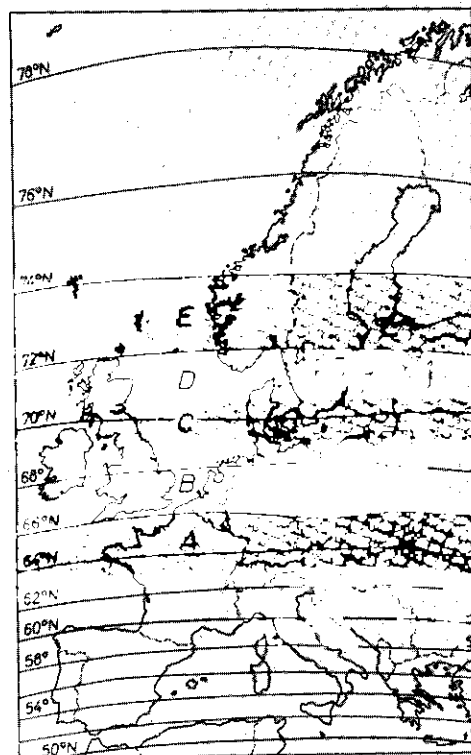


Fig. 2. Map of Europe with different zones (A, B, C, D, E) of observing stations limited by lines of equal dip angle I (magnetic latitude).

the general relationship between the degree of geomagnetic activity and the probability of occurrence of aurora backscatter communications and the influence of magnetic dip angle I on this relationship. Investigations of this kind had not been done in the publications mentioned before in Refs. 2, 4, 5, and 6.

3. INFLUENCE OF GEOMAGNETIC ACTIVITY IN DIFFERENT MAGNETIC LATITUDES

The general relationship between geomagnetic activity and the occurrence of auroral echoes can be investigated by means of the geomagnetic Kp -index. Despite the fact that this is an index based on a 3-hourly interval, whereas aurora contacts can be as short as only a few minutes, it is a useful quantity

to use as a preliminary comparison. The value of Kp has been obtained for the periods when aurora contacts had been reported and then every contact was arranged according to the simultaneous Kp -degree. The result of this procedure is shown in Fig. 3, it shows the influence of the Kp -index on the probability of occurrence of v.h.f. bistatic aurora communications for contacts from zone B (dark zone in the figure) to zones A to E on a frequency of

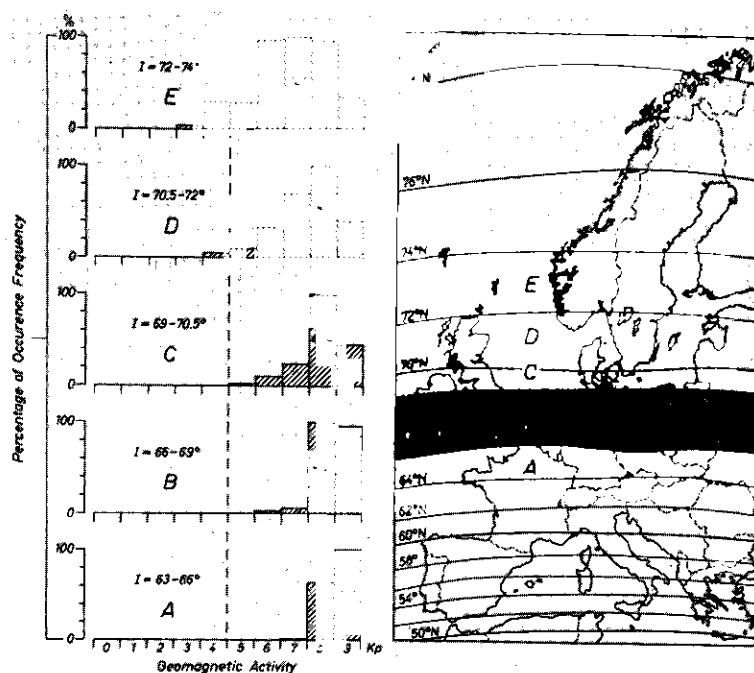


Fig. 3. Influence of the planetary geomagnetic activity Kp on the probability of occurrence of v.h.f. bistatic aurora backscatter communications for contacts from zone B (dark zone in the figure, dip angle $I = 66^\circ - 69^\circ$) to zones $A-E$ according to amateur observations on 145 Mc/s from 1957 to the beginning of 1963. The number in the 100 per cent column of each diagram ($A-E$) gives the number of aurora contacts which corresponds 100 per cent.

145 Mc/s. The upper diagram E in Fig. 3 shows the Kp influence on the communication frequency from zone B to E (the most northern one) and the lower diagram A the Kp influence on the communication frequency from zone B to A (the most southern one). The highest occurrence frequency of aurora contacts has been made to 100 per cent in every diagram of Fig. 3. In the upper diagram E the highest frequency of 100 per cent (which occurs at $Kp = 7$) corresponds to 141 aurora contacts. In the lower diagram A the highest frequency of 100 per cent (which occurs at $Kp = 9$) corresponds to 101 aurora contacts. 100 per cent does not mean in these cases that aurora communication is possible during 24 hr of a day, but only the highest probability of occurrence. This kind of standardization makes it easier to compare the different diagrams in Fig. 3.

According to the upper diagram E in Fig. 3 the highest communication probability occurs at $Kp = 6-8$ with maximum at $Kp = 7$. At $Kp = 4$ and 5 aurora contacts are possible with about 30 per cent of the maximum occurrence frequency. During geomagnetic quiet conditions, $Kp = 0-2$, no communications are possible. The maximum frequency of aurora communications shifts from $Kp = 7$ in diagram E to higher Kp values if one moves to

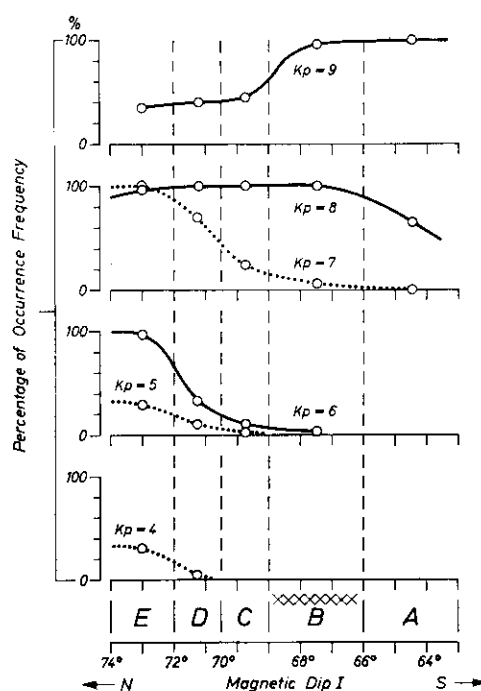


Fig. 4. Influence of magnetic dip I on the probability of occurrence of v.h.f. bistatic aurora backscatter communications from zone B ($I = 66^\circ-69^\circ$) to zones A-E during different degrees of geomagnetic activity Kp . Same frequency and observation data as in Fig. 3.

the more southern zones D, C, B, and A. The highest frequency of aurora communications from zone B to A (the most southern one) occurs at $Kp = 9$. Aurora contacts within zone B and from B to A are nearly impossible during $Kp = 6$ and 7, contrary to contacts from B to E, which are possible with maximal probability during these two Kp degrees.

The results from Fig. 3 are shown in a somewhat different method of representation in Fig. 4. The magnetic dip scale from $I = 63^\circ-74^\circ$ with the limits of the zones A-E is drawn horizontally, and vertically, as in Fig. 3, the percentage of occurrence frequency of aurora contacts for different Kp degrees. During $Kp = 9$ (upper diagram in Fig. 4) the highest probability occurs for communications from zone B to A (the most southern one). During $Kp = 6$ and 7 the highest probability occurs for communications from zone B to E (the most northern one). During $Kp = 4$ and 5 aurora

communication practically is possible only from zone *B* to *E* but with much smaller probability than during $Kp = 6$ and 7. During $Kp = 8$ the highest frequency occurs for communications within zone *B* and from *B* to *C* and *D*, which are located in the middle. Figure 4 shows distinctly that the maximum

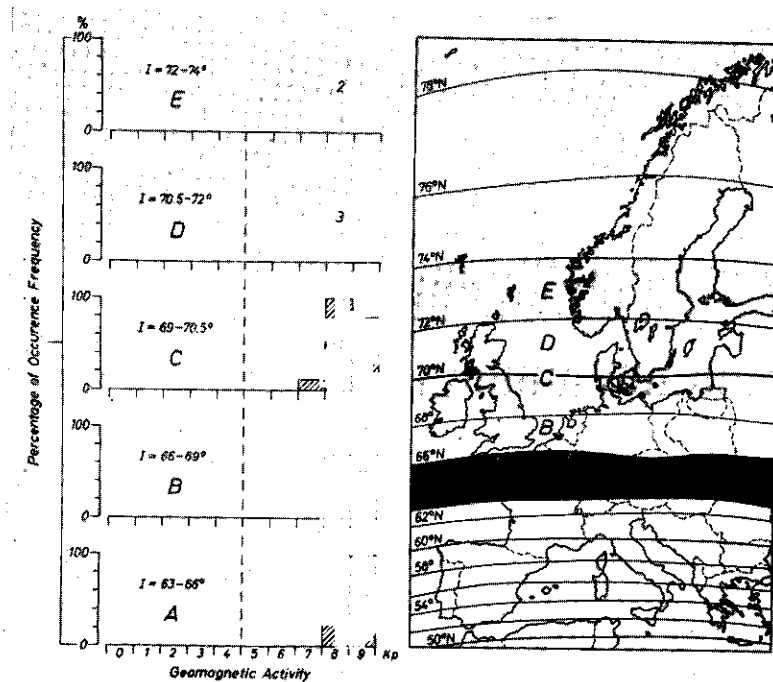


Fig. 5. Similar experiment as in Fig. 3 but for aurora contacts from zone *A* (dark zone in the figure) to zones *A*-*E*. Same frequency and observation data as in Fig. 3.

communication probability from *B* to the other zones moves from the most southern to the most northern one with decreasing Kp degree.

The result of a similar experiment as in Fig. 3 is shown in Fig. 5 but for communications from zone *A* (the most southern one) to *A*-*E*. As can be seen in the figure, contacts from zone *A* to *D* and *E* (the most northern ones) are practically impossible. The two communications to *E* and the three to *D* are exceptions, probably caused by extraordinary ionospheric or tropospheric conditions. According to diagram *C* in Fig. 5 the highest communication probability occurs at $Kp = 8$. During $Kp = 0-6$ (geomagnetic quiet and moderate disturbed conditions) no communication is possible. The maximum frequency of aurora communications shifts, similar to Fig. 3, from $Kp = 8$ in diagram *C* to $Kp = 9$ if one moves to the more southern zones *A* and *B*.

4. AN ATTEMPT TO INTERPRET THE RESULTS

The reduction of v.h.f. radar echoes from aurora has shown, that these echoes can only be obtained from a very restricted strip of sky corresponding to the region where the line of sight from the radar location to the aurora intersects the local geomagnetic field lines at right angles (see e.g. Refs. 8, 9, 10). There is thus a fundamental difference between the visual and radio-echo observations in that visual forms can be observed if they occur anywhere above the horizon whereas radio echoes are detected only if the ionization within the region of the auroras is located within the specular reflecting region. Figure 6 shows the geometry of the v.h.f. aurora backscatter problem. On condition that perpendicularity is necessary, aurora displays at the points *A* and *B* in Fig. 6 used to give backscatter-echoes, but not displays at the points *C* and *D*.

It has been found by a more detailed reduction of radar aurora backscatter observations that the echoes originate in average from a height interval from about 100 to 120 km with a maximum at 110 km^{9,10} and that for obtaining echoes the tolerance in deviation from perpendicularity is about ± 2 to 3° .^{11,12}

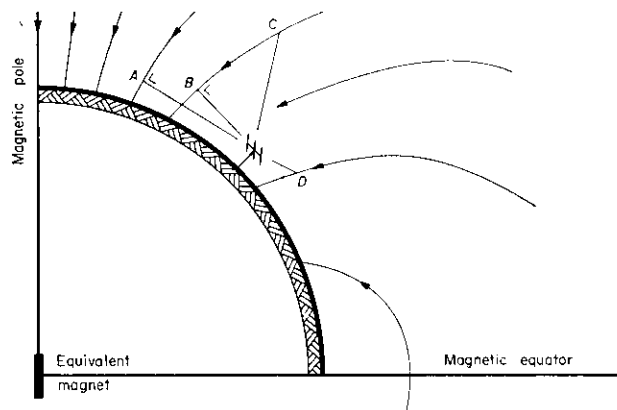


Fig. 6. *v.h.f.-radio waves aurora backscatter are only possible, when the direction of radio-wave-propagation and the direction of the lines of force of the earth's magnetic field are perpendicular at the reflection point. Under this assumption aurora displays at the points *A* and *B* used to give backscatter-echoes, but not displays at the points *C* and *D*.*

In exceptional cases this deviation can be greater. One reason for this is probably the fact that the geomagnetic field lines can change their orientation during a magnetic storm. Störmer¹³ describes an analysis of the movements of the radiant point of coronal forms. This point was traced through a movement of as much as three degrees in inclination during the course of the great auroral display of 22–23 March 1920. The auroral rays forming the corona are aligned with the geomagnetic field, and their motion reflects a similar distortion of the local magnetic field, probably at 200–300 km heights. As the disturbance current system during a geomagnetic storm is

usually considered to flow in the E -layer, one would expect any field distortions to be as great or greater than those occurring higher up

Figure 7 shows in diagram I a cross-sectional view of the earth in the geomagnetic north-south direction together with the approximate orientation of the geomagnetic lines of force H in space. The zero-point left corresponds to $\Phi = 54^\circ$ geomagnetic latitude. The diagram II shows the deviation from

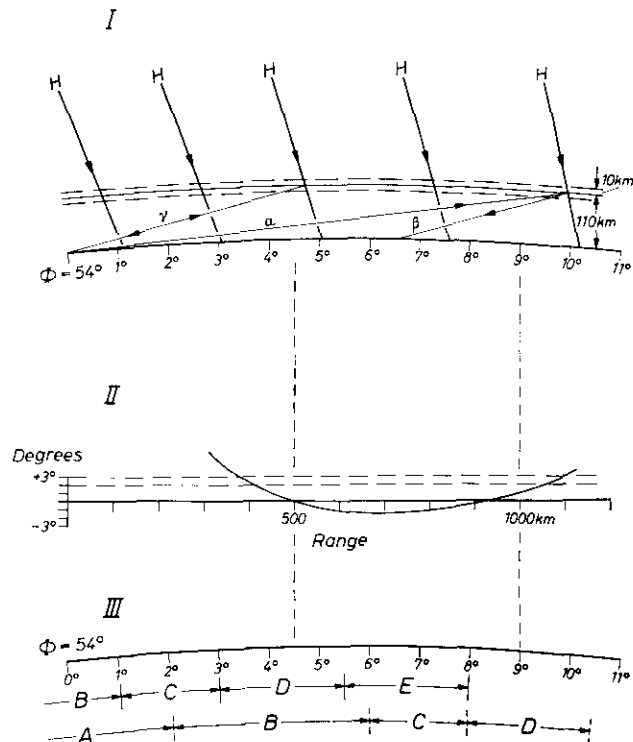


Fig. 7. Cross-sectional view of the earth in the geomagnetic north-south direction together with the approximate orientation of the geomagnetic lines of force H in space (diagram I). Diagram II: Deviation from perpendicularity of a straight line from $\Phi = 54^\circ$ to geomagnetic north crossing the geomagnetic field lines in 110 km height as a function of distance. Diagram III: Limits of the zones B-E from Fig. 2 in geomagnetic latitude degrees along the $93^\circ E$ geomagnetic meridian.

perpendicularity of a straight line from $\Phi = 54^\circ$ to geomagnetic north crossing the geomagnetic field lines in 110 km height (the most frequent altitude of reflecting centers) as a function of distance. Diagram III shows the limits of the zones B-E (from Fig. 2) in geomagnetic latitude degrees along the $93^\circ E$ geomagnetic meridian. This meridian leads through Middle Europe. The lower line in diagram III approximately shows these limits for the zones A-E, but this is not quite correct since the center of A along the $93^\circ E$ geomagnetic meridian is about $4-5^\circ$ south of $\Phi = 54^\circ$, but for a comparison one can use this rough approximation. As can be seen from diagram II

in Fig. 7 exact perpendicularity at 110 km height is obtained at 500 and about 930 km distance. A deviation of $\pm 3^\circ$ from perpendicularity is obtained in the range interval from about 370 to 1100 km. It results from other calculations that perpendicularity within $\pm 3^\circ$, seen from zone *E* (the most northern one) to northern direction, starts at about 3.5 latitude degrees (≈ 390 km) from *E* to larger distances. The results mentioned before indicate that the geometry of aurora communication from zone *B* to *E* is along propagation path α and β in diagram I of Fig. 7 and the backscattering center must be located about 1100 km north from zone *B*. Contacts from *B* to *E* are most frequent during $Kp = 6$ and 7 (Fig. 3, diagram E) but contacts within zone *B* occur very seldom during these two Kp degrees. This means that a propagation path along path α and back in diagram I, Fig. 7 occurs very seldom, probably it is only possible during strong geomagnetic storms with changing of magnetic dip angle or by slight bending of the path in the ionosphere or by meteorological influences in the troposphere. Communications within region *B* are most frequent during $Kp = 8$ and 9 (Fig. 3). In these cases the backscattering centers must have moved more to the south so that a shorter propagation path is possible, similar to that of γ in diagram I, Fig. 7, which fulfils the perpendicularity condition.

Figure 5 shows that communication is nearly impossible from zone *A* to *D* and *E*. From diagram I, Fig. 7 it can be seen that in these cases the backscattering center must be located more than 1100 km north of region *A* where certainly no perpendicularity within $\pm 3^\circ$ can be obtained. The little exceptions in Fig. 5, diagrams D and E, obviously were caused by extraordinary conditions, e.g. deviation of magnetic dip during an extreme geomagnetic storm or bending of the propagation path in the troposphere or ionosphere.

5. CONCLUSIONS

The results shown in Figs. 3–5 indicate, together with the restriction to special propagation paths in bistatic aurora backscatter communications caused by the perpendicularity condition (Fig. 7), that the backscattering centers shift to southern latitudes with increasing Kp degree similar to the southward movement of visual aurora displays and of the geomagnetic S_d -current system¹⁴ with increasing geomagnetic activity.

The results in Figs. 3–5 further indicate that the maximum possibility for bistatic aurora communications in the regions from $I = 63^\circ$ to 74° moves from $Kp = 6/7$ to higher Kp values if the central point of the air line between two stations getting in wireless contact via aurora shifts to southern latitudes.

Aurora communications in the north–south direction are possible under ordinary conditions on 145 Mc/s up to air line distances of about 800 km in regions of magnetic dip angle from $I = 63^\circ$ to 74° . Higher distances, however, are only very seldom possible.

6. ACKNOWLEDGEMENTS

The author wishes to express his thanks to many European radio amateurs for the careful and extended observations of aurora communications and to the DARC (Deutscher Amateur Radio Club = German Amateur Radio Club) for collecting the comprehensive observation data. Here is a good

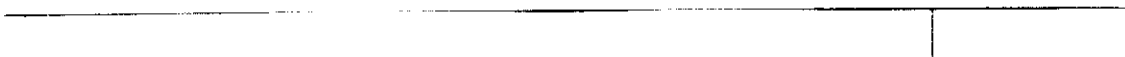
example of amateur radio supplying research information difficult and very expensive to obtain in any other way.

Most of the observation data used for this investigation are published in detail in Ref. 15 with support of the Academy of Science at Göttingen (Germany). The results of further reductions of the data in Ref. 15 are published by the author in Refs. 16 and 17.

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OBSERVATIONS DURING NUCLEAR TESTS



The following page(s) provide higher quality versions of graphics contained in the preceding article or section.

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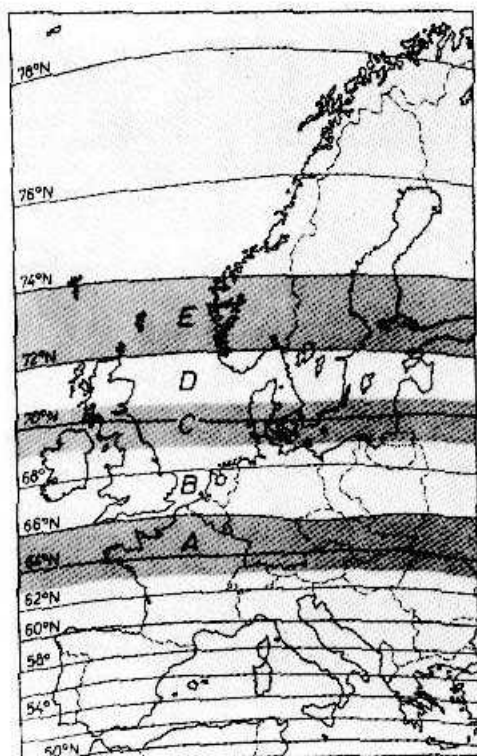


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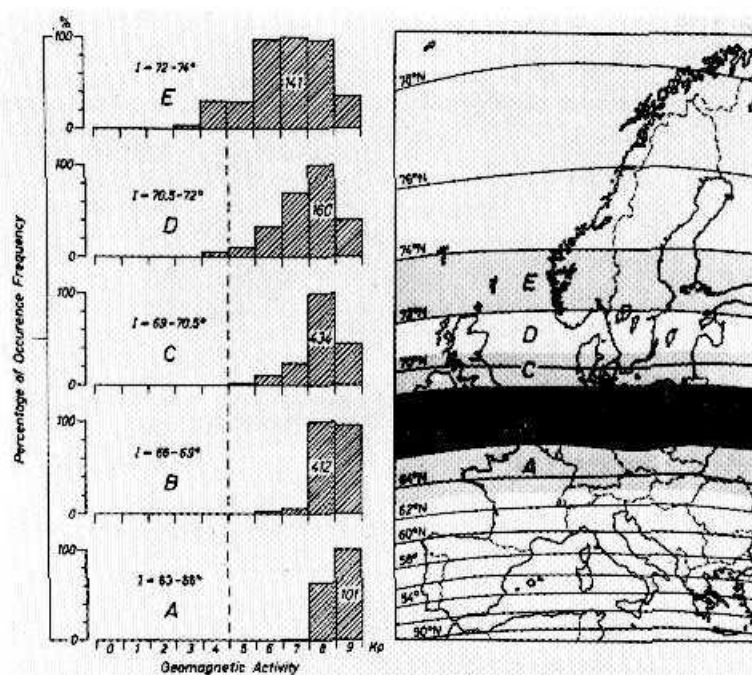


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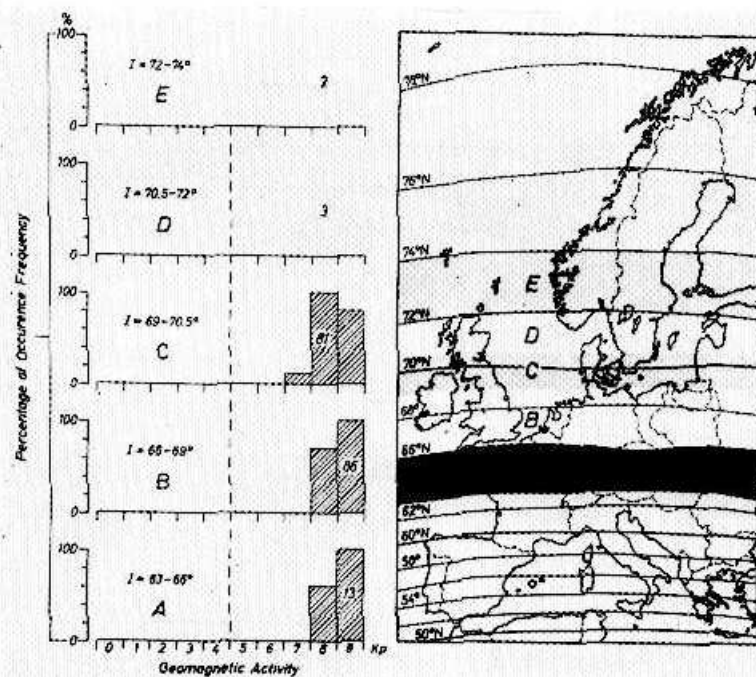


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